

## Is there a narrow $N(1685)$ ?

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(Dated: January 31, 2017)

The helicity-dependent observable  $E$  for the reaction  $\gamma d \rightarrow \eta n(p)$  with a spectator proton was recently measured by the A2 Collaboration at MAMI in Mainz. The data were interpreted as further evidence for a narrow resonance with spin and parity  $J^P = 1/2^+$  ( $P_{11}$  wave). However, a full partial wave analysis without any narrow resonance leads to an excellent description of the data; imposing a narrow resonance with the properties suggested by the A2 Collaboration leads to a significant deterioration of the fit quality: there is no need for a narrow resonance.

A narrow structure was observed at a mass of about 1685 MeV in the  $\gamma d \rightarrow \eta n(p)$  excitation function [1–7]. The structure was interpreted [8, 9] as the non-strange member of the antidecuplet of pentaquarks with spin-parity  $J^P = 1/2^+$  predicted by Diakonov, Petrov, and Polyakov [10]. In 2012, the observations reported in [1, 3, 6] were introduced into the Review of Particle Properties (RPP) under the heading of a new one-star nucleon resonance  $N(1685)$  [11] but was removed from the listings in the most recent issue of RPP [12]. The interpretation of the structure as narrow resonance was supported by further studies [13–16], the results reported in [17] were ambiguous.

However, also coupled-channel and interference effects of known nucleon resonances have been discussed in the literature to explain the narrow structure. The Gießen group interpreted the narrow dip in the  $\gamma d \rightarrow \eta n(p)$  excitation function as  $N(1650)1/2^-$  and  $N(1710)1/2^+$  coupled-channel effect [18], Shyam and Scholten assign the dip to interference effects between the  $N(1650)1/2^-$ ,  $N(1710)1/2^+$ , and  $N(1720)3/2^+$  resonances [19]; alternatively, the dip could be produced to effects from strangeness threshold openings [20].

The narrow dip can, however, also be explained naturally by interference effects in the  $J^P = 1/2^-$  wave [17, 21–23]. In [23], the precise data reported by the A2 Collaboration at MAMI [4, 5] were used to study the structure. It was found that it can be explained quantitatively by interference of the two nucleon resonances  $N(1535)1/2^-$  and  $N(1650)1/2^-$  within the  $J^P = 1/2^-$  partial wave. Fits which included a narrow  $J^P = 1/2^+$  resonance returned a zero production strength. If the properties of the narrow  $J^P = 1/2^+$  resonance as reported in [4, 5] were imposed, the fit deteriorated significantly.

Recently, the A2 Collaboration at MAMI reported a measurement of the helicity-dependent double polarization variable  $E$  of the  $\gamma d \rightarrow \eta n(p)$  reaction [24] where  $E = (\sigma_{1/2} - \sigma_{3/2})/(\sigma_{1/2} + \sigma_{3/2})$ , with  $\sigma_h$  being the cross section for  $\gamma d \rightarrow \eta n(p)$  with neutron and photon spin aligned (helicity  $h = 3/2$ ) and or opposite ( $h = 1/2$ ). The data show clearly that the structure originates from the  $h = 1/2$  contribution. The authors fitted the angular

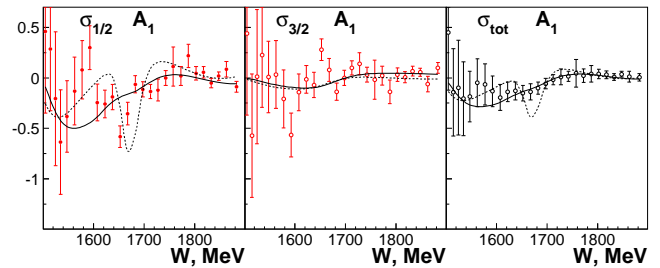


FIG. 1: Legendre coefficients of the angular distributions of  $\sigma_{1/2}$ ,  $\sigma_{3/2}$  [24], and  $\sigma_{\text{tot}}$  for the reaction  $\gamma d \rightarrow \eta n(p)$  where  $\sigma_{\text{tot}}$  is calculated as  $(\sigma_{1/2} + \sigma_{3/2})/2$ . The experimental results (red circles) are compared to a BnGa fit without a narrow resonance (solid curve) or a fit imposing a narrow resonance (dotted curve).

distributions (five data points per energy interval) with third-order Legendre polynomial functions and found a narrow dip at 1650 MeV in the first order Legendre coefficient. They concluded: *The extracted Legendre coefficients of the angular distributions for  $\sigma_{1/2}$  are in good agreement with recent reaction model predictions assuming a narrow resonance in the  $P_{11}$  wave as the origin of this structure.* In this paper we will show that their conclusions are incompatible with the data.

As a first step, we repeated the fit with Legendre polynomials. Figure 1 shows the first-order Legendre coefficients  $A_1^{\sigma_{1/2}}$ ,  $A_1^{\sigma_{3/2}}$ , and  $A_1^{\sigma_{\text{tot}}}$  as functions of the  $n\eta$  invariant mass for fits to the angular distributions of  $\sigma_{1/2}$ ,  $\sigma_{3/2}$ , and  $\sigma_{\text{tot}} = (\sigma_{1/2} + \sigma_{3/2})/2$ . The coefficients  $A_0^{\sigma_{1/2}}$ ,  $A_0^{\sigma_{3/2}}$ , and  $A_0^{\sigma_{\text{tot}}}$  are similar to the corresponding total cross sections, the coefficients  $A_2$  and  $A_3$  for the cross sections  $\sigma_{1/2}$  and  $\sigma_{3/2}$  are shown in [24]. In the coefficient  $A_1^{\sigma_{1/2}}$  there is indeed a narrow dip at about 1650 MeV. Since the  $J^P = 1/2^-$  partial wave dominates the reaction, significant contributions to  $A_1^{\sigma_{1/2}}$  have to come from the interference between the  $J^P = 1/2^-$  partial wave and  $P$ -wave contributions. Indeed, a comparison of  $A_1^{\sigma_{1/2}}$  with fit results shows that a model assuming no  $N(1685)$  (Fig. 1, solid curve) does not reproduce the narrow dip while a model which includes a narrow  $N(1685)$  (Fig. 1, dotted curve) gives qualitative agree-

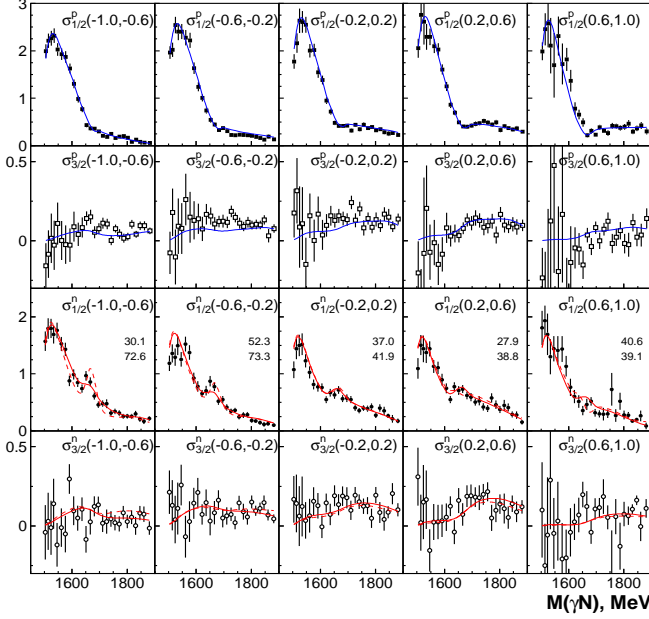


FIG. 2: Excitation functions  $\sigma_{1/2}$  and  $\sigma_{3/2}$  for 5 bins in  $\cos\theta_\eta^*$  for the reaction  $\gamma d \rightarrow \eta p(n)$  (top 2 rows) and  $\gamma d \rightarrow \eta n(p)$  (bottom 2 rows) and new BnGa fits. The data are from [24], statistical and systematic errors are added quadratically. The solid lines represent the BnGa fit without an additional narrow resonance, the dashed lines a fit in which a narrow resonance is imposed with the properties given in [4]. The two numbers give the  $\chi^2$  contribution of the bin, the upper number without, the lower number including the narrow resonance.

ment between data and prediction. These observations are the basis for the conjecture in [24] that a narrow resonance has been observed. There are, however, a few arguments which disagree with this conjecture.

The dip in  $A_1^{\sigma_{1/2}}$  is statistically significant. Relative to the solid line (representing the fit with no  $N(1685)$ ), the dip in  $A_1^{\sigma_{1/2}}$  has a mean deviation  $-0.24 \pm 0.04$  and contributes  $\chi^2 = 15.9$  for two data points. However, there is a peak in  $A_1^{\sigma_{3/2}}$  as well, at the same mass and of similar size and shape as the dip in  $A_1^{\sigma_{1/2}}$ . The peak deviates from the solid line by  $+0.25 \pm 0.04$ , contributes  $\chi^2 = 12.7$ , and is thus of similar importance as the dip. The coefficient  $A_1^{\sigma_{\text{tot}}}$  follows precisely the fit with no  $N(1685)$ , the data are compatible with the fit, with  $\chi^2 = 2.1$  for the two data points. If the dip in  $A_1^{\sigma_{1/2}}$  had a physical significance, it should be seen in  $A_1^{\sigma_{\text{tot}}}$  with a strength as given by the dotted line. But it is not. There is hence the suspicion that the dip might be a statistical fluctuation: a small change in the observable  $E$  may lead to a disappearance of the dip and the peak.

To test this hypothesis, we performed overall fits. In these fits most particle properties are frozen to the values derived from fits to pion and photo-induced reactions off protons. For  $\gamma n$  reactions we use the data listed in [23] and, in addition, the new MAMI data [24]. The latter data are shown in Fig. 2 and Fig. 3, the solid line is

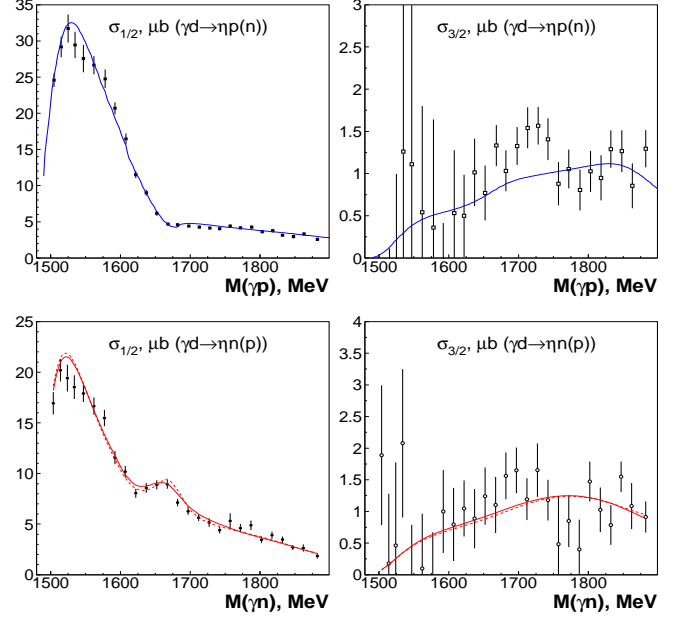


FIG. 3: The total cross sections  $\sigma_{1/2}$ ,  $\sigma_{3/2}$  for the reactions  $\gamma d \rightarrow \eta p(n)$  (top) and  $\gamma d \rightarrow \eta n(p)$  (bottom) and new BnGa fits. The solid lines represent a fit without a narrow resonance, the dashed lines in the bottom figure represent a fit in which a narrow resonance is imposed with the properties given in [4].

our fit without introduction of a narrow resonance. For the differential cross sections from [4, 5] and [24], the fit returns a  $\chi^2_{\text{MAMI}} = 1205$  for 1150 data points. Obviously, there is no need to introduce  $N(1685)$ . When  $N(1685)$  was enforced in the fit with properties as given in [4], i.e. with  $M = 1670$  MeV, width  $\Gamma = 30$  MeV, and  $\sqrt{Br(\eta n)} A_n^{1/2} = \bar{a} [\text{GeV}^{-\frac{1}{2}} 10^{-3}] = 12.3 [\text{GeV}^{-\frac{1}{2}} 10^{-3}]$ , the fit returned  $\chi^2_{\text{MAMI}} = 1834$  for the 1150 data points from [4, 5, 24]. The  $\chi^2$ 's for the new data from [24] are shown in Fig. 2 for each angular bin of  $\sigma_{1/2}$  for  $\gamma d \rightarrow \eta n(p)$ , the sum is  $\chi^2 = 187.9$  for the fit without narrow resonance and 265.8 when it is imposed.

If the production strength is fitted freely, it reduced to  $1.2 [\text{GeV}^{-\frac{1}{2}} 10^{-3}]$  and the total  $\chi^2$  improved by 12 units to 1193. This production strength corresponds to a contribution which is about 100 times smaller than the contribution claimed in [4, 5]. Fig. 4 shows how the  $\chi^2$  increases with the strength of an imposed narrow  $N(1670)$ .

The new data on  $E$  for the reaction  $\gamma d \rightarrow \eta p(n)$  – with a spectator neutron – in [24] differed significantly from first BnGa fits which were performed before the data on double-polarization observables on  $\gamma p \rightarrow \eta p$  on protons became available [25]. To explore this discrepancy, we included the new MAMI data for  $\eta$  production off protons (bound in deuterons) [24] in the fits. Figures 2 and 3 show that the new data can be included in the fit without any problems, after a slight tuning of the parameters. In Table I, we show the helicity amplitudes obtained in the new fit in comparison to the fit presented in [23].

TABLE I: Helicity amplitudes determined from a fit without a narrow  $N(1685)$  resonance. The T-matrix couplings are the quantities which are listed in the RPP; K-matrix couplings are given in addition. The new results are compared to those obtained in [23] which are listed in small numbers. The comparison shows the impact of the new data from [24] and [25].

		$N(1535)1/2^-$ $N(1650)1/2^-$					$N(1535)1/2^-$ $N(1650)1/2^-$		
$p$	<u>T-matrix</u>	$0.093 \pm 0.009$	$0.032 \pm 0.006$	$\text{GeV}^{-1/2}$	$n$	<u>T-matrix</u>	$-0.088 \pm 0.004$	$0.016 \pm 0.004$	$\text{GeV}^{-1/2}$
	[23]	$0.114 \pm 0.008$	$0.032 \pm 0.007$	$\text{GeV}^{-1/2}$		[23]	$-0.095 \pm 0.006$	$0.019 \pm 0.006$	$\text{GeV}^{-1/2}$
	<u>Phase</u>	$8 \pm 4^\circ$	$7 \pm 7^\circ$			<u>Phase</u>	$5 \pm 4^\circ$	$-28 \pm 10^\circ$	
	[23]	$10 \pm 5^\circ$	$-2 \pm 11^\circ$			[23]	$8 \pm 5^\circ$	$0 \pm 15^\circ$	
	<u>K-matrix</u>	$0.112 \pm 0.008$	$0.075 \pm 0.006$			<u>K-matrix</u>	$-0.160 \pm 0.030$	$-0.052 \pm 0.005$	
	[23]	$0.096 \pm 0.007$	$0.075 \pm 0.007$			[23]	$-0.120 \pm 0.006$	$-0.052 \pm 0.006$	

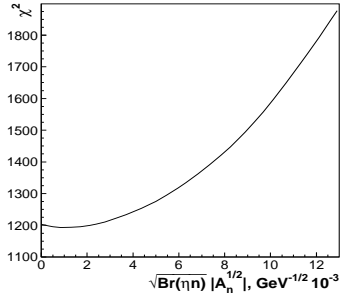


FIG. 4: Increase of  $\chi^2$  when a narrow resonance with mass  $M = 1670$  MeV, width  $\Gamma = 30$  MeV, and  $J^P = 1/2^+$  is imposed as a function of the signal strength  $\tilde{a} = \sqrt{Br(\eta n)} A_n^{1/2}$ . The number of data points is 1150.

The changes in the photocouplings of  $N(1535)1/2^-$  and  $N(1650)1/2^-$  for protons are likely due to the inclusion of the new data on  $\gamma p \rightarrow \eta p$  [25].

Summarizing, we have studied the new data on the helicity dependence of the reaction  $\gamma d \rightarrow \eta n(p)$  with a spectator proton measured by the A2 Collaboration at MAMI in Mainz [24]. We cannot confirm the conclusions of the authors that the dip in the first-order Legendre coefficient in an expansion of the angular distributions of  $\sigma_{1/2}$  is due to a narrow  $J^P = 1/2^+$  resonance. First, the dip is accompanied by a peak in the first-order Legendre coefficient of  $\sigma_{3/2}$  of the same shape suggesting that the dip is due to a statistical fluctuation in the measurement of  $E$ . Second, a partial wave analysis without a narrow  $J^P = 1/2^+$  resonance is excellent, the inclusion of it with the reported properties leads to a significantly worse description of the data.

Comments of Bernd Krusche and Volker Metag to an early version of this comment are kindly recognized. The work was supported by the *Deutsche Forschungsgemeinschaft* (SFB/TR110), the *U.S. Department of Energy* (DE-AC05-06OR23177), and the *Russian Science Foundation* (RSF 16-12-10267).

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